**Why Double Side Skin Bulk Carrier? – Study from a Strength Viewpoint**

Vincent (Shou-Hsiung) Hsu*, Bor-Chau Chang and Hong-Chung Chen

*Senior Naval Architect, Bureau Veritas Research Department*

*67/71 Boulevard du Chateau, 92571 Neuilly-Sur-Seine, France*

*e-mail: vincent.hsu@bureauveritas.com*

**Abstract**

With the rejection of double side skin (DSS) mandated proposal for bulk carrier by IMO’s Marine Safety Committee in 2004, the bulk carrier owners will become much more hesitant on deciding the type of their ships. This paper is to show some strength advantages of DSS bulk carriers based on real design experiences. DSS in a bulk carrier is initially designed to support the shearing force, especially for bulk carrier with alternative loading condition. However, compared to single side skin (SSS) design, experiences had proved that the DSS design also has very good transverse strength performance which often is responsible for some losses of bulk carriers. Two state-of-the-art capesize DSS bulk carriers and one capesize SSS bulk carrier are chosen in this paper to investigate the above-mentioned advantages of DSS design. Besides, a real failure case of side frames in an aged capesize SSS bulk carrier is investigated to show the risks behind the SSS design. Finally, some figures of comparison in cargo hold volume and steel weight of the different designs are provided.

**Keywords:** Double side skin (DSS), Single side skin (SSS), Capesize bulk carrier.

1. **INTRODUCTION**

The idea for double side skin (DSS) to become mandatory for bulk carrier was first introduced at the 68th session of the IMO Marine Safety Committee (MSC68) held in 1997. In MSC68 a new SOLAS Chapter XII was proposed, and its draft was issued in IMO’s sub-committee on Design and Equipment committee (DE47) in 2004. In the same year (2004), the DSS mandated proposal in SOLAS Chapter XII was overturned in MSC78. Although the DSS design was not made mandatory, it is believed that more DSS bulk carriers will be built in the future. Before the MSC78, there were a lot of bulk carrier orders in shipyards due to very booming bulk marketing and some bulk carrier operators decided to choose DSS design. During this period of time, the authors had opportunities to design and assess strength of some state-of-the-art capesize DSS bulk carriers and single side skin (SSS) bulk carriers. All the new designs were based on the latest regulations and their strength performance were found to be very different. DSS in a bulk carrier is initially designed to support the shearing force, especially for bulk carrier with alternative loading condition. However, when compared to SSS design, experiences had proved that the DSS design also has very good transverse strength performance which often is responsible for some tragedies of bulk carriers. To investigate the strength advantages of DSS design, two state-of-the-art capesize DSS bulk carriers and one capesize SSS bulk carrier are chosen to be analysed in this paper. Because the side-frame structures are probably the weakest parts in SSS bulk carriers, some studies had been done to assess their strength performances.

Nakai et al. [1] [2] had studied effect of pitting corrosion on local strength of hold frames of SSS bulk carriers. Their studies showed pitting corrosion, the most frequent type of corrosion, could largely reduce the tensile and buckling strength of the side frames of SSS bulk carriers. Ozguc et al. [3] investigated the capability of collision resistance and residual strength in collision damage for SSS and DSS bulk carriers. The study showed the DSS bulk carriers have much higher safety factor than the SSS ones when subjected to collision damage. There are a lot of damaged reports related to the side frames of SSS bulk carriers, and one damaged capesize SSS bulk carrier delivered in 1991 was selected for the case study. Its damaged situation showed very clearly the side shell collapse was due to failure of side frames. Some factors concerned by owners are believed to be the main reasons for the abandon of IMO’s plan to make double hulls mandatory. Among the factors, loss of cargo-hold volume and...
increase of material cost are two of the greatest importance. Based on existed data of the sample ships, this paper also reveals the extent to which the above-mentioned factors are affected.

2. MAIN CHARACTERISTICS OF SAMPLE SHIPS

In this session the philosophy of structural designs of the three sample ships: ships A, B and C are introduced. The main particulars of the sample ships are listed in Table 1 and their simple midship sections are shown in Fig. 1 to 3. The contents of IACS unified rules (UR) applied in the structural design of the sample ships are listed in Table 2.

Table 1. Main particulars of the sample ships

<table>
<thead>
<tr>
<th></th>
<th>Ship A</th>
<th>Ship B</th>
<th>Ship C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length B.P.(m)</td>
<td>281.5</td>
<td>281.5</td>
<td>290.5</td>
</tr>
<tr>
<td>Breadth (m)</td>
<td>45.0</td>
<td>45.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>24.1</td>
<td>24.1</td>
<td>24.4</td>
</tr>
<tr>
<td>Draft (scant.)</td>
<td>17.78</td>
<td>17.78</td>
<td>18.1</td>
</tr>
<tr>
<td>DSS width (mm)</td>
<td>0</td>
<td>1500</td>
<td>5400</td>
</tr>
</tbody>
</table>

Fig. 1 Midship section of ship A

Fig. 2 Midship section of ship B

Fig. 3 Midship section of ship C

Table 2. IACS unified rules applied

<table>
<thead>
<tr>
<th></th>
<th>IACS UR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship A</td>
<td>S1, S1A, S12, S17, S18, S20, S21</td>
</tr>
<tr>
<td>Ship B</td>
<td>S17, S18, S20, S21R1, S26, S27, S30</td>
</tr>
<tr>
<td>Ship C</td>
<td>S1, S1A, S17, S18, S20, S21(R3), S25, S26, S27, S28</td>
</tr>
</tbody>
</table>
3. **STRENGTH PERFORMANCE**

Shear strength assessment is very important for bulk carriers with alternative heavy loading condition. The thickness of side shell plate of SSS bulk carrier is always have to be increased in addition to the water pressure requirement due to shear strength insufficiency. Moreover, side frames and their attached side shell of SSS bulk carrier are believed to be one of the most vulnerable parts of its design.

**Shear strength**

The above-mentioned situation of insufficient shear strength in SSS bulk carrier will become worse after further considering flooding condition for application of IACS UR S17. Fig. 4 shows the side shell reinforcement of ship A due to shear strength insufficiency after considering flooding condition. The shell thickness is originally 20 mm of high tensile steel, but after considering the required shear strength the thickness of shell plate near to transverse bulkhead have to be increased to 25.5 mm with the same material.

For DSS bulk carriers, the shearing force is supported by the longitudinal bulkhead (LBHD) and the side shell, the supporting ratio can be obtained by the following equation [4]:

\[ F = 2(\alpha_s F + \alpha_L F) \]  

where \( F \) is shearing force, \( \alpha_s \) and \( \alpha_L \) are supporting ratio coefficients for LBHD and side shell respectively.

From equation (1), one obtains:

\[ \alpha_s + \alpha_L = \frac{1}{2} \]  

(2)

Furthermore,

\[ \alpha_L = K \alpha_{L0} \]  

(3)

\[ \alpha_{L0} = \frac{t_L}{2(t_L + t_s)} \]  

(4)

where \( t_L \) means the minimum plate thickness of longitudinal bulkhead and \( t_s \) means the minimum plate thickness of side shell. \( K \) depends on the distance between the longitudinal bulkhead and the center line and has maximum value 1.23 when the inner bulkhead lies at quarter of the ship breadth. Besides, the value of \( K \) will decrease to 1.0 when the LBHD comes to the side shell position. From equation (4), we also see \( \alpha_{L0} \) and then \( \alpha_L \) can be increased by enlarging the minimum thickness of the LBHD. Usually, the outer shell of DSS bulk carrier is not to be reinforced for shear strength. It means there is always margin of shear strength for side shell of DSS bulk carriers. The experiences in ship B & C (both are DSS designs) show there is no side shell reinforcement due to shear strength insufficiency.

To check the shear strength of the side shell for the three sample ships, a computer package MARS developed by BV and can be downloaded from internet is used to calculate the shear stress induced by vertical shear force for the midship sections of the sample ships. The shear stress distributions induced by an assumed vertical shear force 1,000 KN are shown in Fig.5 to 7 for ships A, B and C respectively.

From the shear stress calculation we see the shear stress levels of shell are quite different between SSS and DSS bulk carriers. For a 1,000 KN vertical shear force, the maximum shear stress of ship A is 11.75 N/mm², but the maximum shear stresses are only 6.78 N/mm² and 5.76 N/mm² for ship B and C respectively. It means the shell plate thickness of ship A is dominated by shear stress, while the shear strength of outer shell for ship B and C have a safety margin of up to 40 percent.

**Transverse strength**

In addition to the shear strength, a series of three-hold scope finite element analyses (FEA) are carried out for each sample ship. The FEA models (portside only) with deformation and Von-Mises stress distribution for the three sample ships are shown on Fig. 8.

Because transversal displacement of the side structures is a very important index to predict the transverse strength performance of the side structures, the maximum transversal displacement relative to the almost fixed transversal bulkhead of each sample ship is investigated. Fig. 9 shows the transversal displacement for side internal structures for Ship A and Ship B with side shell and inner bulkhead (for Ship B only) been erased for easy viewing. The maximum transversal displacements for the Ship A and Ship B are 16.4 mm and 13.1 mm respectively. It means that the maximum transversal displacement of Ship B is about 80% of Ship A.

From the results of the above-mentioned numerical analysis, it’s very clear the transverse webs in DSS design with the highest stress level are prevented by LBHD and inner bottom from exposing to a high corrosive cargo.

---

**Note:** The equation (2) and (3) have been renumbered and simplified for clarity. The original equations are denoted as (2) and (3) in the original text. The renumbering and simplification are done to maintain consistency and clarity in the text. The original equations are:

\[ F = 2(\alpha_s F + \alpha_L F) \]  

(1)

\[ \alpha_s + \alpha_L = \frac{1}{2} \]  

(2)

\[ \alpha_L = K \alpha_{L0} \]  

(3)

\[ \alpha_{L0} = \frac{t_L}{2(t_L + t_s)} \]  

(4)
environment. However, the stress intensive areas of side frames in SSS design are totally exposed to the cargos.

**Fig. 4** Side shell reinforcement of ship A

**Fig. 5** Shear stress distribution of ships A

**Fig. 6** Shear stress distribution of ships B

**Fig. 7** Shear stress distribution of ships C

**Fig. 8** FEA models (portside only) with deformation and Von-Mises stress distribution

**Fig. 9** Transversal displacement of side structures for Ship A & B
4. SIDE FRAME BUCKLING OF A SSS DAMAGED CASE

A damaged capesize SSS bulk carrier with nine (9) cargo holds is investigated in this section based on criteria of IACS UR S31 to show the weakness of the side frame structures in the SSS design.

Damage description

The damaged ship delivered in 1991 with deadweight (DWT) 149,000 tons was sailing its voyage with alternatively full loading and got No.3 cargo hold flooded. More than a half of the side structures including shell plate and side frames had been disappeared. The vessel was taken over by a salvage company and had been successfully rescued. From the damaged condition of the adjacent No.4 cargo hold which was almost empty and still intact as shown in Fig.10 and 11, we can imagine the flooding scenario of the broken No.3 cargo hold. The cargo-hold flooding is due to collapse of the side structures. From Fig.10, because some frames were buckled with flanges still intact, we believe the side frames were firstly buckled and then lead to the failure of flanges of their lower brackets. The gauging data showed some plates of the lower brackets had been corroded up to 25% of its initial thickness and the corrosion type was mostly pitting corrosion.

Finite element buckling strength assessment

To verify the residual buckling strength of the side frames in the middle (No.4) cargo hold, a three dimensional (3-D) FEA model and a two dimensional (2-D) fined mesh model were built as in the Fig. 12 and Fig. 13 to carry out the FEA. FEM computational packages MSC/Patran and MSC/Nastran [5] are used to carry out the linear buckling strength assessment by using Lanczos method as the eigenvalue extraction method. Based on the study of Nakai et al. [2], the uniform corrosion based on the gauged data can be used to model the randomly pitting corrosion with little difference in deformation and ultimate strength behaviors of the side frames. The corrosion percentages used in the FEA model of the related structures are listed in Table 3.

The loading condition is set to be the real situation of fully loading before flooding of the ship. The cargo weight is 8,000 tons in the middle cargo hold and 23,500 tons in the adjacent cargo holds. The wave pressure distribution is based on formulas in IACS UR S31.3.1.2 (Rev.3, 2005) with scantling draught 17.3m and is described as follows:

Wave pressure:
(i) Below water line:

\[ p_1 = 1.50 \left( p_{11} + 135 \right) \left( \frac{2}{89.75} - 1.2(T - z) \right) \]

\[ p_{11} = 3k_C + k_f = 35 \cdot 0.368, \quad k_f = C_b = 0.86 \]

\[ C = 10 \cdot 0.75 - \left( \frac{300 - L}{100} \right)^{0.5} = 10 \cdot 0.464 \]

(ii) Above water line:

\[ p_1 = p_{1,ul} - 7.5(z - T) = 90 - 7.5(z - T) \]

The Von-Mises stress distribution on the deformed 3-D FEA model is show in Fig. 14. As shown in Fig. 15, we find the maximum Von-Mises stress for lower part of the side frame web aligned with transverse web in hopper tank is about 37.1 kg/mm² which have slightly exceeded the yielding stress 36 kg/mm² for AH36 high tensile steel. The middle side frame aligning with transverse web in hopper tank in No.4 cargo hold is then chosen to be meshed finer as shown in Fig. 13 for eigenvalue buckling check. In Fig. 13, the mesh size is 6 elements along width of flange and 10 elements along depth of web, so there are enough grid points for expected buckling shape. Besides, all the elements are 2-D shell elements and all nodal displacements (translational and rotational) from the 3-D FEA are translated to the 2-D fine-mesh model at their corresponding nodes as the enforced displacements for the 2-D FEA.

The result of linear buckling calculation shows the lowest eigenvalue for possible buckling mode is 0.995 that means the residual buckling strength is not enough for the assessed loading condition. Fig. 16 shows the buckling mode shape for eigenvalue 0.995 and Fig. 17 shows the detailed buckling shapes viewed from different directions for the lower bracket of the side frame.

From Fig. 17, we can see the flange located at the upper radius end of the lower bracket has the maximum displacement after buckled and it is expected to damage first. Compared to the damaged side frames shown in Fig. 10 and Fig. 11, the calculation is believed to be very reasonable for the possible damaged scenario. To avoid the
above-mentioned buckling failure, we believe it is necessary to replace the side frames based on the procedures specified in the IACS UR S31.

**Fig. 10** Damage of side frames in No.4 cargo hold (pictured by Vincent Hsu)

**Fig. 11** Damage of side frames in No.4 cargo hold (detailed) (pictured by Vincent Hsu)

**Fig. 12** 3-D FEA model for Ship D

**Fig. 13** 2-D fined mesh FEA model for Ship D

**Fig. 14** Von-Mises stress distribution with deformation

**Fig. 15** Von-Mises stress distribution of side frames and webs in hopper tank
### Table 3. Corrosion percentages

<table>
<thead>
<tr>
<th>Plate</th>
<th>corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom, Shell.</td>
<td>10 %</td>
</tr>
<tr>
<td>Inner bott., Floor, Upp. deck, Transverse web, Side frame (upper part),</td>
<td>20 %</td>
</tr>
<tr>
<td>Hopper sloped plate</td>
<td>25 %</td>
</tr>
<tr>
<td>UWT sloped plate, Coaming, Girder, Stool, Corrugated BHD</td>
<td>25 %</td>
</tr>
<tr>
<td>Side frame (lower part),</td>
<td>25 %</td>
</tr>
<tr>
<td>Others</td>
<td>20 %</td>
</tr>
<tr>
<td><strong>Longitudinal &amp; Stiffener</strong></td>
<td>25 %</td>
</tr>
</tbody>
</table>

**Fig. 16** Buckling mode with eigenvalue 0.995

**Fig. 17** Buckling mode detail with eigenvalue 0.995 (seeing from different direction)

### 5. OTHER ASPECTS OF DSS DESIGN

In addition to the strength advantages of the DSS BC, the most important aspects related to the Owners’ future maintenance cost are specified in this section based on the real design.

Among the owners’ concerns, the steel weight increased and the cargo-hold volume decreased may be the most important. Table 4 shows the figures of comparison between Ship A and Ship B for the related aspects. Compared to the SSS design of Ship A, the steel weight is increased 3.55% and cargo-hold volume excluding hatch way is decreased 3.54% for the DSS design of Ship B.

### Table 4. Comparison between Ship A and Ship B for the related aspects

<table>
<thead>
<tr>
<th>Sample Ship</th>
<th>Steel weight (ton)</th>
<th>Cargo Volume (m³) (exclude hatch way)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship A</td>
<td>20,290</td>
<td>192,260</td>
</tr>
<tr>
<td>Ship B</td>
<td>21,010</td>
<td>185,450</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

Risk behind the SSS bulk carriers cannot be overlooked due to much lower side structures safety margin than DSS bulk carrier. Compared to the vulnerable side structures of SSS bulk carrier, analyses in this paper show DSS bulk carrier has much better shearing and transverse strength. Data obtained by comparing ship A and ship B also shows the cargo hold volume lost and steel weight increased for DSS design is very little for capsize bulk carrier and the extent to affect the operating cost of owners can be rationally neglected. DSS bulk carriers are now much more often the favors of some bulk carrier operators than ever before.
REFERENCES


